Influence of Lipid Composition on the Water and Fat Exudation and Gel Strength of Meat Batters

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ABSTRACT

Blends of lard with eight separate fats or oils (70:30 w/w) were prepared and used as the fat component of meat batters. After cooking, the batters were analyzed for water and fat exudation and gel strength. None differed significantly from the control of 100% lard. Positive correlation coefficients, however, were significant between percent monounsaturated triglycerides and water exudation, polyunsaturated triglycerides and fat exudation and saturated triglycerides and gel strength. Addition of lecithin, cholesterol or methyl palmitate to the lard increased fat exudation and decreased gel strength. Sodium laurate had the opposite effect whether added to the lard or to the aqueous phase.

INTRODUCTION

LOWERING SALT LEVELS in comminuted meat products to reduce dietary sodium intake necessitates a stringent process control to avoid failure of the meat batter. This requires more complete knowledge of the factors that lead to a successful product.

The physical structure of meat batters has been described both as an emulsion and as a suspension of solid fat particles (Swasdee et al., 1982; Honikel, 1983). If it is a true emulsion, the chemical composition of the lipid phase would be expected to affect the physical properties of the batter. If the batter is a suspension, the hardness and melting point of the fat would be the major controlling parameters.

Initial studies on the role of lipid composition in emulsion stability utilized the liquid oil-meat extract model system of Swift et al. (1961). Twenty-six fat and oil samples were tested for emulsification ability (Christian and Saffle, 1967). The magnitude of the differences found between the lipids was small. They noted that more short-chain and monounsaturated triglycerides were emulsified than were other triglycerides. Frazen and May (1968), however, found no difference between various blends of corn oil with coconut oil, linseed oil or lard.

Studies using a meat batter also gave equivocal results. Rendered beef and pork fats were fractionated into four portions having widely differing melting characteristics (Swift et al., 1968). The most stable batters were produced in the portion with the highest melting temperature. Chicken frankfurters made with chicken, beef or pork fat or cottonseed oil were firmest with beef fat or cottonseed oil when tested at ambient temperature but not when heated (Baker et al., 1969). Townsend et al. (1971) found that frankfurters made with beef fat, pork fat and cottonseed oil had similar physical properties, although beef fat required a higher chopping temperature. Histological examination of these frankfurters showed the hardness of the fats was related inversely to the ease of dispersing the fats into a fine, stable emulsion (Ackerman et al., 1971). Chattoraj et al. (1979) reported that the poor dispersibility of sheep and goat fat was improved by mixing with 50% peanut oil. Lee et al. (1981a, b) concluded the emulsion stability and physical properties of the frankfurter were directly related to the fat hardness and melting properties.

The purpose of this work was to determine whether the lipid phase affects the functional properties of a meat batter. The forming and cooking of the batters closely modelled commercial manufacturing and this work would determine the batter stability through the heat setting of the gel. Composition of the batters was changed from the standard formulation and the resulting changes in the three functional properties of the batter (water exudation, fat exudation and gel strength) were monitored. The understanding of the physiochemical nature of a meat batter might lead to improvements in the physical characteristics of batters made with reduced levels of salt.

MATERIALS & METHODS

Materials

Fresh beef bottom rounds and pork back fat tissues were obtained from local abattoirs. The beef was trimmed of fat and gross connective tissue and stored at 1°C. Both fresh and frozen adipose tissue was used. Samples were analyzed for protein, fat, and moisture by Tecator Kjeldahl, Soxhlet and oven drying methods, respectively (AOAC, 1984). The beef lean and pork fat were ground separately through a 3/16 in. (5 mm) plate prior to use.

Fat was rendered from ground pork adipose tissue by heating on a hot plate under a stream of nitrogen up to a maximum temperature of 125–145°C. The liquid lard was filtered through glass wool and blended while liquid (ca 100°C) with other natural fats and oils at a ratio of 70:30 (w/w). The blends were cooled at room temperature (22°C) before storing at 1°C. Cocoa butter was obtained from Cortes Hnos & Co., Cpor A (Dominican Republic); coconut oil from Industrial Products Group, Stokely Van-Camp Inc. (Indianapolis, IN); olive oil from Filippo Berio (Lucca, Italy); tallow and hydrogenated tallow from Michigan Shortening Co. (Detroit, MI); commercial sunflower oil from Wesson; and safflower oil from Hollywood Health Foods. Butter oil was obtained by melting butter and decanting off the fat through glass wool to remove precipitated proteins. Other lipids were reagent grade except for commercial soybean lecithin. These were blended into a liquid lard in quantities from 1 to 5% (w/w).

Formulation and processing

Procedures for making batters and analyzing for fat and water exudations and gel strength were similar to those used by Whiting (1984). The standard batter formulation of 180g contains 95g lean beef, 49g pork lard, 32g ice and 3.6–5.0g NaCl. The batter composition would be approximately 12% protein, 25% fat, 59% water, and 2.0–2.8% salt. All ingredients were added to the chopping bowl of a food processor (Cuisinart CFP-9) and chopped with brief interruptions to scrape the sides of the bowl and to measure the temperature until 16.0 ± 0.5°C was reached (ca 85 sec). The pH of the uncooked batters was measured by insertion of a combination electrode and automatic temperature compensator directly into the batter.

Three 30 ± 0.1g aliquots of the batter were weighed into 50 mL glass centrifuge tubes (i.d. 2.5 cm) and centrifuged at 200 x *g* for 10 min. The centrifuge tubes were stoppered and placed into a 70–75°C water bath to cook for 30 min. Immediately after removal from the water bath, the water and fat exudates were decanted into calibrated conical 15 mL centrifuge tubes for measurement.

The gel remaining in the centrifuge tube was allowed to cool to room temperature. Gel strength was determined by placing the centrifuge tube vertically in a rack placed on the platen of an Instron Universal Testing Machine, forcing a 1/4 in. (0.64 cm) diameter, flat-bottomed rod through the gel at 50 mm/min and recording the maximum force (grams) of the initial penetration.

Analytical procedures

Thermal properties of the fat blends were determined on a differential scanning calorimeter (Perkin Elmer 990 Thermal Analyzer). The first warming curve of a 30 mg sample was measured by heating from -10°C to 70°C at a rate of 5°C/min. The percent melted fat at 16°C was approximated by dividing the area of the calorimeter curve below 16°C by the total area and multiplying by 100.

The iodine number of the fat blends was determined by the Wijs method (AOAC, 1984). The hardness of the blends was measured by keeping the samples that had cooled overnight at 1°C on ice until immediately before measurement on the Instron. A 1/4 in. (0.64 cm) diameter flatbottom plunger was forced into the fat sample at 100 mm/min. The peak force (grams) of the initial penetration was recorded.

Statistical analyses

Three analytical tests were averaged from each batter to make a single replicate. The data were analyzed by analysis of variance using Duncan's multiple range test and Dunnett's test to compare each treatment to the control, both at the 95% probability level (Steel and Torrie, 1960). Simple correlation coefficients were also calculated using each blend as a data point (n=9).

Results & Discussion

THE WATER EXUDATION TEST measured the tendency of a frankfurter batter to lose water during smokehouse cooking (Meyer et al., 1964; Townsend et al., 1968). Fat exudation indicated whether a batter would fail resulting in fat caps inside the casing or fat losses when reheated by the consumer. Penetration force was a simple measure for the strength and elasticity of the heat-set gel. These three functional properties also give an indication of the biochemical interactions of the meat proteins, specifically protein-water, protein-lipid, and protein-protein, respectively.

The standard salt level (2.2%) was varied from 2.0–2.8% for different batches of meat so that the control batch exhibited measurable water and fat exudations. Changes in lipid composition could then show an increase or decrease in the exudations.

The thermal characteristics of the blends containing 30% natural lipids in lard show a wide variety of melting behaviors (Fig. 1). The first heating curves were used as they would reflect most closely the phase changes of fat during the commercial frankfurter manufacture (Rossell, 1967). However, rendered pork fat does not have thermal behavior identical to pork adipose tissue (Swift et al. 1968; Townsend et al., 1968). Also, rendered fats are generally known to be inferior to adipose tissue for making meat batters (Honikel, 1983).

Peaks indicating phase changes between -10° to 5°C were unsaturated triglycerides, and transitions above 20°C were from saturated triglycerides. Composition of the blends was calculated from data in USDA (1979) Handbook 8-4 (Table 1). Safflower and sunflower oils were high in polyunsaturated triglycerides, olive oil contains large amounts of monounsaturated fats (C18:1); coconut oil has lauric acid (C12:0); butter oil contained triglycerides of short chain fatty acids; coconut, cocoa butter, tallow and hydrogenated tallow were higher in saturated triglycerides than lard. The iodine numbers of the blends reflected the compositions; lard had a normal value of 65 (Dugan, 1971), the blends high in polyunsaturated lipids (safflower and sunflower) and monounsaturated lipids (olive) had higher values. The blend with hydrogenated tallow has the lowest iodine number.

The percent lipids in the blends melted at 16°C ranged from 16 to 75%. For lard and most blends, the 16°C chopping temperature was between the two major endothermic peaks. Pork fat does not liquify below 20°C (Honikel, 1983). Townsend et al. (1968) noted that the instability of emulsions comminuted to temperatures above 18.5°C coincided with the onset of melting of the high-melting portions of the fats.

The hardness was also related to the composition, thermal behavior and iodine number, but the range was much greater. At 1°C the safflower, sunflower, and olive oil blends were very soft and nearly liquid, whereas coconut oil, cocoa butter and hydrogenated tallow blends were very hard.

Despite large differences in composition and physical characteristics of the blends, the water and fat exudations and gel strength did not differ (Dunnett's test $p \geq 0.05$) from the 100% lard control. Although fat exudation was higher for the highly unsaturated blends (safflower, sunflower and olive), differences from the lard control were nonsignificant. However, the correlation coefficient between percent saturated fats and fat exudation was -0.78 and between percentage polyunsaturated fats and fat exudation was 0.64, both significant ($p \geq 0.5$) (Table 2). This resulted because the fat compositions of the blends were used when calculating the correlation coefficients, whereas they were not for the analysis of variance. The correlation coefficients were therefore, more sensitive measures of an effect of lipid composition. Because compositions were expressed as percents of the three classes of triglycerides, if one of the three components were positively correlated,there would be a tendency for another to be negatively correlated. The iodine number was also significantly correlated to fat exudation. In emulsions containing 22% fat, Swift et al. (1968) found the high melting fractions (saturated triglycerides) produced more stable emulsions.

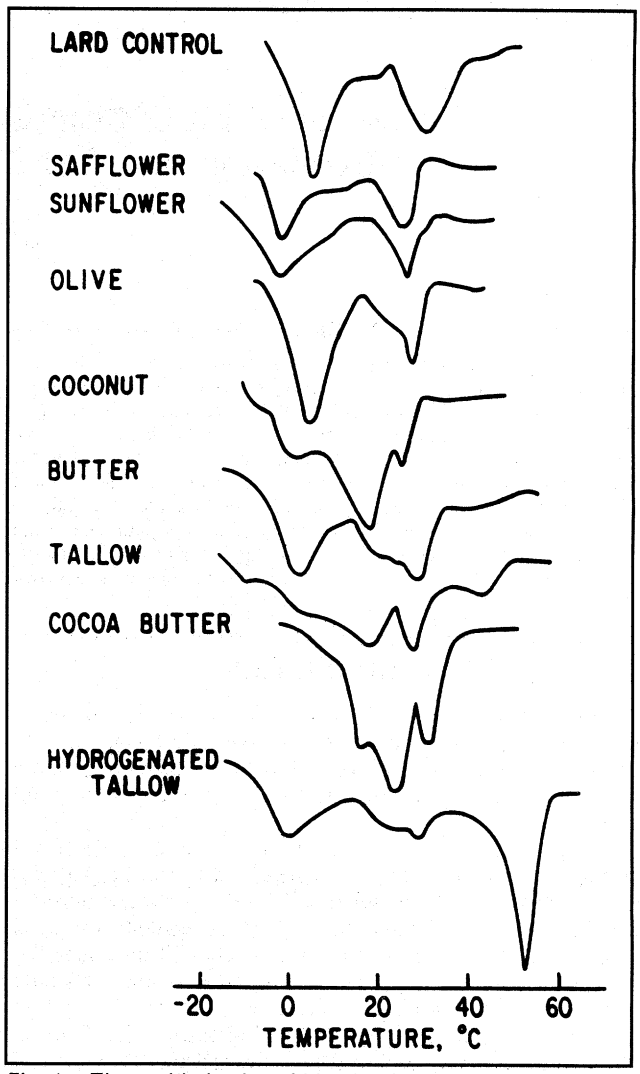

Fig. 1. Thermal behavior of blends of 30% fats or oils in lard. Endothermic peaks point downward.

Gel strengths of batters made from any blend did not differ from those made from lard. However, cooked batters made with hydrogenated tallow had greater gel strength than those made from the three highly unsaturated blends (Duncan's multiple range test) (Table 1). Significant correlation coefficients were also found between percent saturated fats and gel strength ($r = -0.91$) and between polyunsaturated fats and gel strength and ($r = -0.68$). That gel strength emulsion stability varied with the fat hardness agreed with studies by Lee et al. (1981a, b). The correlation coefficient between gel strength and fat hardness in this study was 0.82. These observations are consistent with the model of a batter being primarily a suspension of fat particles in a viscous protein matrix and not a true emulsion. Studies have found poorer emulsion stability when the melting point was too high (Ackerman et al., 1971; Chattoraj et al., 1979) but this may reflect a limitation of the equipment's ability to chop the fat into sufficiently small particles.

The effect of additions of relatively small amounts of pure lipids to the lard on the batters is shown in Table 3. The thermal transitions

Table 1—Properties of natural fat blends and the functional properties of meat batters made from the blends

	100% Lard (Control)	Blended fat							
		Safflower	Sunflower	Olive	Coconut	Butter	Cocoa butter	Tallow	Hydrogenated tallow
Calculated composition[a]									
% Saturated	41	31	31	32	55	48	47	44	58
% Monounsaturated	47	36	38	56	34	42	44	46	33
% Polyunsaturated	11	31	29	10	8	9	9	9	8
Iodine Number	65	102	82	78	47	62	55	54	50
% Melted at 16°C	63	62	75	68	62	47	16	45	24
Hardness (g)	273	20	27	23	1773	617	2647	987	3350
Water Exudate[b] (% batter)	9.1	9.4	7.6	12.6	9.4	8.3	10.9	7.4	7.9
Fat Exudate[b] (% batter)	0.6	4.8	6.1	6.7	0.3	0.8	1.9	0.5	2.0
Gel strength[b] (g)	490	189	218	222	497	445	515	503	600

[a] USDA (1979)

[b] All water exudates, fat exudates and gel strengths are not significantly different from lard control ($p > 0.05$) ($n=3$, each in triplicate).

Table 2—Simple correlation coefficients between triglyceride composition and functional properties

	Correlation coefficient			
	Hardness	Water exudate	Fat exudate	Gel strength
% Saturated	0.84	−0.28	−0.78	0.91
% Monounsaturated	−0.43	0.59	0.23	−0.34
% Polyunsaturated	−0.54	−0.18	0.64	−0.68
Iodine Number	−0.73	0.20	0.77	−0.82

$r \geq 0.63$ for $p \leq 0.05$ ($n=9$)

were nearly identical (data not shown), and the percent lipid melted at 16°C was relatively consistent. Hardness was also much more uniform then before. The 5% tristearin did decrease the percent melted fat and increase hardness, while addition of 1.25% methyl linoleate plus 1.25% methyl linolenate had the opposite effect. Lecithin, cholesterol and methyl palmitate were generally detrimental to the functional properties. Only sodium laurate improved them.

Frazen and May (1968) noted that concentrations of phospholipid above 150 mg per 100 mg protein in an oil-extracted protein model system increased the amount of oil emulsified. Our lecithin concentrations were less than 5 mg/100g. Meyer et al. (1964) using a similar model system found lecithin did not improve the emulsion stability. Emulsifiers with either high or low hydrophilic-lipophilic balance values (HLB) all decreased stability. Honikel (1982, 1983) reported lecithin had a detrimental effect on cooking losses in Brühwurst mixtures.

In this experiment the physical characteristics of the blends were similar, yet large differences were found in the cooked batters and indicated that the chemical properties of minor components of the lipids would affect the quality of the meat batter. These results suggested interactions between lipids and proteins occurred, indicating, in part, an emulsion.

Because addition of sodium laurate improved the batter, further experiments were conducted with it. Different techniques for adding laurate did not affect laurate's ability to improve functionality (Table 4). All laurate additions were equivalent to 1.4% of the batter. Water exudation for the rendered fat control and the adipose tissue control were the same, but the fat exudation was much greater for the rendered fat control. As expected, the gel strength was less in the rendered fat batter (Honikel, 1983). The water losses and fat exudations were nearly eliminated with any of the laurate additions. Laurate added to the adipose tissue treatments produced the greatest gel strength. Interestingly, laurate was equally as effective when added to the aqueous phase as when added as part of the lipid phase (rendered fat). Therefore, in subsequent tests laurate was added as a dry ingredient to formulations using adipose tissue.

Table 5 shows the effect of differing sodium laurate concentrations in the batter on the three functional properties. There was a 2.5% salt control and a 1.5% reduced salt series with 0–1.4% laurate (0–5% lipid).

Water exudation doubled with reduction in salt, and 0.14% laurate reduced the exudation to an amount equivalent to the 2.5% salt level. Greater laurate additions nearly eliminated water exudation. The effect of laurate on fat exudation was similar; all three laurate additions did not differ significantly from the 2.5% salt control. The gel strength was reduced by the lower salt levels, but the laurate restored it. The gel strength of the reduced-salt batter was different from the 2.5% control at the 94% confidence level and the two higher laurate additions were greater ($p \leq 0.05$) than the 1.5% salt without laurate batter. Unfortunately, an objectionable soapy flavor was noted by the author with all concentrations of laurate used. Although no nitrite or spices which might mask the flavor were included in these batters, batters containing laurate were judged as unlikely to be acceptable at concentrations needed to be effective.

Two other fatty acids, caprylic (C8:0) and myristic (C14:0), were tested to determine whether they might be more effective than laurate (C12:0) and thereby, usuable at lower concentrations (Table 6). Sodium laurate was added at 0.2% and the others were added at equal molarity as fatty acids. Surprisingly, neither was able to improve the three functional properties above the 2.0% salt reference as laurate did. The pH of the raw batters showed the laurate salt increased the pH and the acid form of the other two decreased the pH, but the changes were not considered sufficiently great to account for the observed results. Meyer et al. (1964) commented without presenting data that 3% oleic acid aided emulsification and binding in a sausage emulsion. It is doubtful that such a high concentration of any free fatty acid would be sensorily acceptable.

Triglycerides having increased hardness improve the water and fat exudation and gel strength of meat batters, assuming adequate chopping and dispersion of the fat. This suggested that the batter was a solid suspension with the protein matrix entrapping the fat particles before and after thermal setting of the gel. The gel had to retain the fat when it liquified during the smokehouse cooking and reheating before consumption. The additions of pure lipids suggested that at relatively high concentrations an emulsification effect might also oc-

Table 3—Characteristics and functional properties of meat batters made with lard containing selected lipid components

	Lard (Control)	5% Glycerol	1% Crude lecithin	5% Cholesterol	5% Tristearin	5% Stearic acid	5% Sodium laurate	5% Methyl palmitate	2.5% Methyl linoleate and Methyl linolenate
Iodine #	61	54	67	63	63	76	60	—	71
% Melted at 16°C	56	52	53	60	48	51	52	54	64
Hardness (g)	177	173	137	177	503	150	213	137	68
Water exudate (% batter)	10.6	8.6	17.0[a]	13.5	12.8	11.8	1.6*	11.6	8.4
Fat exudate (% batter)	3.8	0.8	14.6*	14.0*	6.4	4.3	2.1	13.3*	3.3
Gel strength (g)	416	516	186*	157*	336	359	467	154*	365

* Within each row, Dunnett's $p \leq 0.05$ from control ($n=3$, each in triplicate).

[a] Significance $p \leq 0.06$.

Table 4—Functional properties of meat batters with different sodium laurate additions

	Adipose tissue (control)	Laurate powder added at start of chopping	Laurate pre-mixed into ground adipose tissue	Rendered fat	Rendered fat containing sodium laurate
Water exudate (% batter)	12.3	0.0*	0.1*	12.6	0.2*
Fat exudate (% batter)	0.6	0.0	0.0	4.0*	0.0
Gel strength (g)	437	666*	613*	314	461

* Within each row, Dunnett's $p \leq 0.05$ compared to adipose tissue control (n = 3, each in triplicate).

Table 5—Effect of sodium laurate additions on the functional properties of meat batters

% NaCl	2.5	1.5	1.5	1.5	1.5
% Na laurate (% batter)	0	0	0.14	0.56	1.4
Water exudate (% batter)	10.7	16.5*	8.8	0.9*	0.1*
Fat exudate (% batter)	0.3	1.0*	0.5	0.0	0.0
Gel strength (g)	608	419[a]	528	734	643

* Within each row, Dunnett's $p \leq 0.05$ 2.5% salt control unless specified (n = 3, each in triplicate).

[a] Significance $p \leq 0.06$

Table 6—Functional properties of meat batters after additions of caprylate, laurate, and myristate

	Control	Sodium laurate[a]	Caprylic acid	Myristic acid
pH	5.41	5.58*	5.37*	5.39
Water exudate (% batter)	7.6	0.8*	8.6	7.0
Fat exudate (% batter)	0.4	0.0*	0.3	0.2
Gel strength (g)	529	592	549	532

* Within each row, Dunnett's test $p \leq 0.05$ (n = 3, each in triplicate).

[a] Na laurate added at 0.2% of the batter, the others at equal molarity to laurate.

cur. However, these lipids also affected water binding and gel strength implying that their action was also on the gel matrix and not exclusively at the lipid--aqueous phase boundry.

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